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# On the linkage between changes in cloud cover and precipitation extremes over Central India

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ABSTRACT

In this study, linkage between changing characteristics of precipitation extremes and cloud covers over Central India is explored during summer monsoon period using Satellite data (1998–2015). This is a first attempt to relate the changes in cloud cover to the changes in precipitation extremes. Non-rainy cirrus clouds are excluded from this study. Results show that heavy rainfall ($\geq$ 60 mm/day) is associated with cold cloud tops (Tb $\leq$ 220 K) while moderate rainfall ($<$ 60 mm/day and $\geq$ 20 mm) occurs mostly with middle clouds (Tb $>$ 220 K and $\leq$ 245 K). Low level clouds (Tb $>$ 245 K) are responsible for light rainfall ($<$ 20 mm/day). Increases in top 20%, 10%, 5% and 1% heavy precipitation relate well with the increases in very deep convective, deep convective and convective cloud cover. Among these relations, increase in top 5% heavy precipitation relates best with increase in very deep convective cloud cover. Decrease in bottom 30% low precipitation relates with decrease in low level cloud cover. The results reported in this study fit into the framework of how weather extremes respond to climate change.

## 1. Introduction

Clouds play a crucial role in atmospheric circulation and the hydrological cycle. Changes in cloud cover associated with climate change remain one of the most challenging aspects of predicting future climate change. Many previous investigations have analyzed changes in cloud cover over different parts of the globe (Henderson-Sellers, 1992; Karl et al., 1993, 1995; Croke et al., 1999; Wylie et al., 2005; Warren et al., 2007; Tang and Leng, 2013). Few of these studies show an increase in high cloud cover and decrease in low cloud cover particularly over tropics. Worldwide there are extensive changes in precipitation extremes (Goswami et al., 2006; Lau and Wu, 2007; Liu et al., 2009; Shiu et al., 2012; Villarini et al., 2013; Mishra and Liu, 2014). Lau and Wu (2011) investigated the climatological characteristics of tropical rain and cloud systems over oceanic region in the context of changes in sea surface temperature using Tropical Rainfall Measuring Mission (TRMM) data. However, limited swath over a region from TRMM sensors may miss many convective clouds between two passes over the region. So, possibilities of errors increase in use of polar satellite (TRMM) data to study cloud based climatology especially in the case of short lived convective clouds. Morever, Lau and Wu (2011) did not relate the changes in precipitation to the changes in cloud cover in their study. In fact, no effort has made in past to relate the changes in cloud cover to changes in precipitation as a function of increase in global temperature. This would seem to be a particularly relevant endeavor, given the importance of close association of convective clouds with heavy precipitation and severe weather extremes and their role in the hydrological and energy exchange cycle (Sikka and Gadgil, 1980; Websters and Stephens, 1980), especially during the SW monsoon season. Convective clouds are responsible for heavy precipitation and influence radiative balance

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significantly and play an important role in moisture transportation in the upper troposphere (Hong et al., 2008).

The aim of the present study is to explore the linakge between changes in cloud cover and extreme precipitation from 18 years (1998–2015) of satellite data. The short period is perceived to be inadequate to explore the relation between long term changes in precipitation and cloud cover, however this study represents best possible way to use satellite data to investigate the relationship between changes in cloud cover and precipitation extremes in the context of climate change. Data from the same geostationary satellite to study cloud cover are free from sampling errors, limited spatial coverage and temporal homogeneity (Bellerby and Sun, 2005; Zeweldi and Gebremichael, 2009). Moreover, finer resolution of the satellite data used in the study helps to identify localized convective systems. Previous studies relating cloud covers and precipitation extremes used observational and model reanalysis. Observational data are limited to few locations while reanalysis data has very coarse resolution and thus can not detect localized convective clouds. Thus, the present analysis will rely on TRMM precipitation. In particular, TRMM-3B42 precipitation product (daily accumulated) has shown reasonably good accuracy over India (Mishra et al., 2010; Prakash et al., 2016; Beria et al., 2017) during SW monsoon season. However, precipitation is under/over-estimated over land/ocean due to correction of excessive orography precipitation, under estimation of low precipitation (over arid regions) and calibration issues (Beria et al., 2017; Liu, 2016).

The paper is organised in 4 sections. Section 1 describes the data products and methods. Sections 2 explores the relation between precipitation and clouds Section 3 relates the changes in cloud cover to those in precipitation extremes. Concluding remarks are included in Section 4.

## 2. Data, study area and methods

Brightness temperature data at 11 μm from Meteosat is used to study the changes in cloud cover for the years 1998–2015. Meteosat 7 data from Meteosat First Generation (MFG) has been used in present study. It provides thermal infrared images at half-hourly intervals, with a spatial resolution of 4 km.

The TRMM Multisatellite Precipitation Analysis (TMPA)—3B42 version 7 (V7) dataset is precipitation estimates which is designed to combine precipitation estimates from various satellite systems as well as land surface rain gauge analyses when possible (Huffman et al., 2007). This precipitation product is developed to take the advantage of rich constellation of satellite-borne precipitation sensors. Central part of Indian region has been selected as study area. During summer monsoon the Central Indian region (Fig. 1) experience presence of convective clouds. Central part of the Indian region has been selected as study area because mean and variance of daily summer monsoon rainfall shows reasonably homogeneous variability. Daily precipitation data for the years 1998–2015 is used in present study to explore the changes in precipitation extremes. Daily mean accumulated TRMM-3B42 rainfall data for the South-West (SW) monsoon period (June to September) of 1998–2015 were into 10 bins of equal precipitation amount in increasing order of precipitation intensity. These bins read as 6.25, 10.92, 16.85, 24.43, 31.82, 42.76, 54.69, 74.82, 100.84, and > 100.84 mm/day for Central Indian region during monsoon season. Percentage (of top 10% bin) is calculated from absolute amount by normalizing to the total precipitation of corresponding year. Normalization filters out the fluctuation caused by the interannual variability in the total precipitation and thus tends to give more self-consistent results for the change in precipitation intensity

## 3. Rainfall vs brightness temperature

The major challenge in exploring relationship between rainfall and cloud is to distinguish non-rainy cirrus from deep convective clouds. To delineate cirrus clouds, a technique developed by Adler and Negri (1988) is used in this study. Description of which is given below:

A brightness temperature gradient (ΔTb) and slope (S) are calculated for each local brightness temperature minimum in a $1^\circ \times 1^\circ$ grid box. The terms ΔTb and S are given by Eqs. (1) and (2), respectively:

$$\Delta Tb = Tb_{avg} - Tb_{min}, \text{ and} \quad (1)$$

$$S = 0.568(Tb_{min} - 217), \quad (2)$$

where $Tb_{min}$ is the local minimum for a grid box. $Tb_{avg}$ is the mean brightness temperature. A smaller ΔTb is the indicator of a weak gradient associated with cirrus cloud. All pixels having ΔTb less than S are classified as cirrus clouds.

A large data set is used to collocate rainfall and brightness temperature (from Meteosat) in order to explore the relationship between rain and clouds after removing cirrus clouds.

Fig. 2 shows the scatter plot between rainfall and brightness temperature. Results show that heavy rainfall ($\geq$ 60 mm/day) is associated with cold cloud tops (Tb $\leq$ 220 K) while moderate rainfall (< 60 mm/day and $\geq$ 20 mm/day) occurs mostly with middle clouds (Tb > 220 K and $\leq$ 245 K). Low level clouds (Tb > 245 K) are responsible for light rainfall (< 20 mm/day).

## 4. Relation between changes in cloud cover and precipitation

Coverage of ground based observation system to monitor the cloud cover changes are not spatially and temporally uniform (Mahrooghy et al., 2011). Moreover, the occurrence of high level clouds can be biased in the presence of low level clouds as low level clouds obscure the sky. Brightness temperature information from geostationary satellites can be used to classify the clouds into low, mid and high level clouds (Roca et al., 2002; Mishra et al., 2010). In this study, clouds are classified based on Tb values. After removal

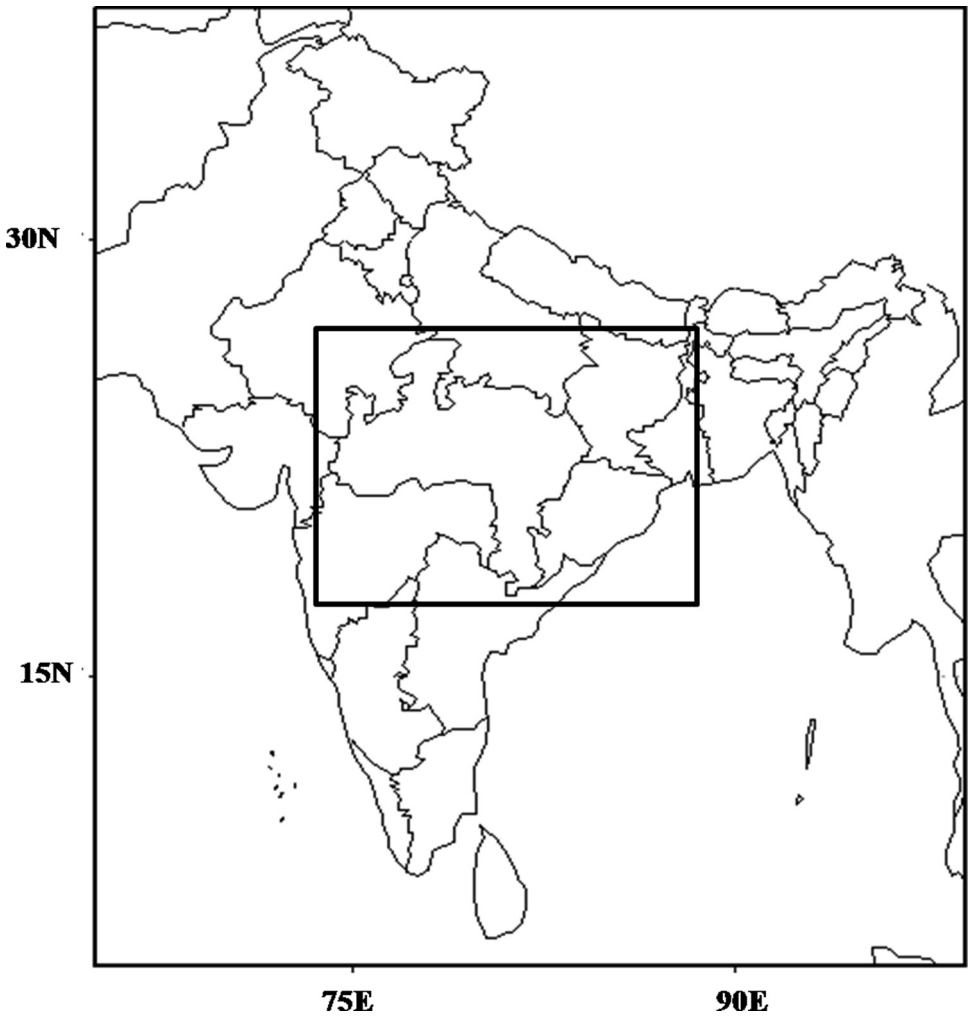


**Fig. 1.** Area of study.

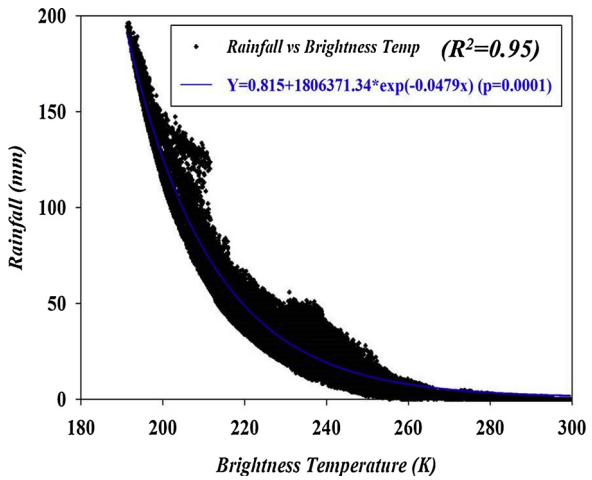


**Fig. 2.** Scatter plot between brightness temperature (BT) and rainfall.

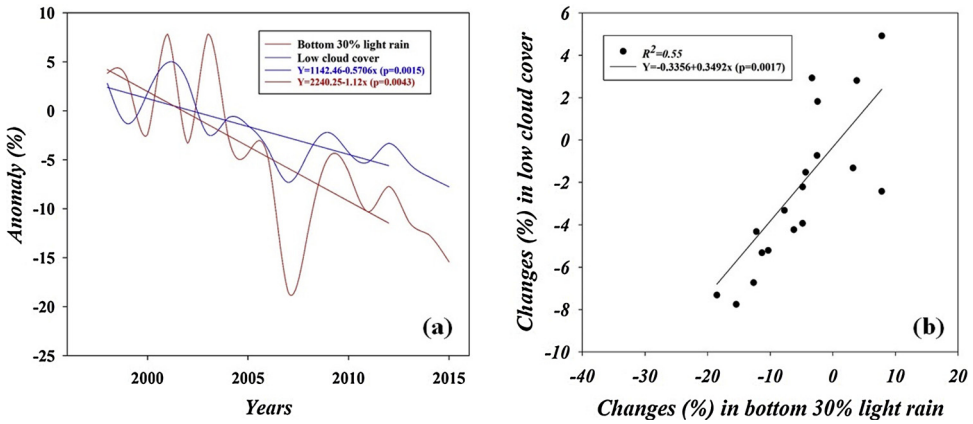


**Fig. 3.** (a) Time series of anomaly (%) of low cloud cover and bottom 30% precipitation, (b) Scatter plot between changes (%) in bottom 30% precipitation and low cloud cover.

of non-rainy cirrus clouds, high clouds are classified into 5 categories i.e. very deep convective clouds (Tb ≤ 200 K), deep convective clouds (200 < Tb ≤ 210 K), convective clouds (210 < Tb ≤ 220 K), mid level clouds (220 < Tb ≤ 245) and low level clouds (Tb > 245 K).

To understand the relation between changes in bottom 30% precipitation and those in low cloud cover, time series of anomaly of low cloud cover and bottom 30% precipitation are examined.

Fig. 3a shows time series of anomaly of low cloud cover and bottom 30% precipitation. It may be seen that changes in bottom 30% precipitation is consistent with those in low cloud cover. Peaks and valleys in 30% bottom precipitation are well reflected by the corresponding peaks and valleys in low cloud cover, suggesting a relationship between them. There is a coefficient of determination ($R^2$) of 0.55 between bottom 30% precipitation and low cloud cover. Moreover, as discussed in previous section using rainfall and Brightness temperature scatter plot, light rain occurs mostly with low clouds (Tb > 245 K). So a decrease in low cloud covers may result in a significant decrease in bottom 30% precipitation. Low clouds have a net cooling effect on the planet and any significant changes in low cloud cover may become very crucial.

Moderate rainfall (< 60 mm/day and ≥ 20 mm/day) has close association with mid level clouds (Tb > 220 K and ≤ 245 K) but no notable changes are observed in mid level cloud cover and moderate rainfall. So possibility of any relationship between changes in mid level cloud cover and changes in moderate rainfall is ruled out.

Fig. 4a–c and d show the time series of anomaly of convective cloud cover and top 20%, top 10%, top 5% and top 1% heavy precipitation, respectively. Changes in heavy precipitation are consistent with the changes in convective cloud cover. These changes in convective cloud cover exhibit a coefficient of determination ($R^2$) of 0.41, 0.77, 0.82 and 0.78 with changes in top 20%, 10%, 5% and 1% precipitation, respectively. There is increase in coefficient of determination (from 0.41 for top 20% to 0.82 for top 5% heavy precipitation) with increase in precipitation intensity up to top 5% precipitation after which coefficient of determination decreases to 0.78 for top 1% precipitation. This may be due to the reason that region of top 1% precipitation is very limited and may have significant presence of orography (Rakhecha and Pisharoty, 1996) and orographic rain is not caused by clouds having very cold brightness temperature (Mishra et al., 2010).

Increases in high cloud covers may indicate an enhanced upward moisture transport which may contribute to increased tropospheric precipitable water. These increases in convective clouds are possibly due to an increase in convective available potential energy over Indian region as observed by Murugavel et al. (2012), which can be caused by an increase in atmospheric lapse rate. Tropospheric lapse rate increases as a result of increase in temperature (Gulev et al., 1991).

Similar changes in cloud covers were also reported but not quantified by Lal et al (2013) over a smaller region of Indo-Gangatic Plain in India. They attributed these changes in cloud cover to Aerosol Index (AI) and found that an increased AI over Indo-Gangatic Plain resulted in an increase in high cloud cover and a decrease in low cloud cover. Persistence of large aerosol loading (a fraction of which is absorbing component) within the core monsoon region acts more as a facilitator in invigorating the monsoon clouds under favorable synoptic condition by suppressing the warm rain, when total cloud fraction is dominated by low clouds (Sengupta et al., 2013). However aerosol effect on clouds and precipitation is not entirely known and requires further research. These changes in cloud covers are related to the changes in precipitation extremes in the next section.

It can be seen for the Fig. 5 that changes in deep convective cloud cover exhibit a coefficient of determination ($R^2$) of 0.49, 0.83, 0.86 and 0.84 with changes in top 20%, 10%, 5% and 1% precipitation, respectively. So changes in heavy precipitation shows better relation with deep convective cloud cover as compared to those with convective cloud cover. Changes in deep convective cloud cover are more severe than those in convective cloud cover.

Finally changes in very deep convective clouds are analyzed along with those in heavy precipitation and results are presented in Fig. 6. Change in very deep convective cloud covers exhibit a coefficient of determination ($R^2$) of 0.53, 0.84, 0.88 and 0.83 with changes in top 20%, 10%, 5% and 1% precipitation, respectively. Changes in very deep convective cloud cover show the best relation with changes in top 5% heavy precipitation.

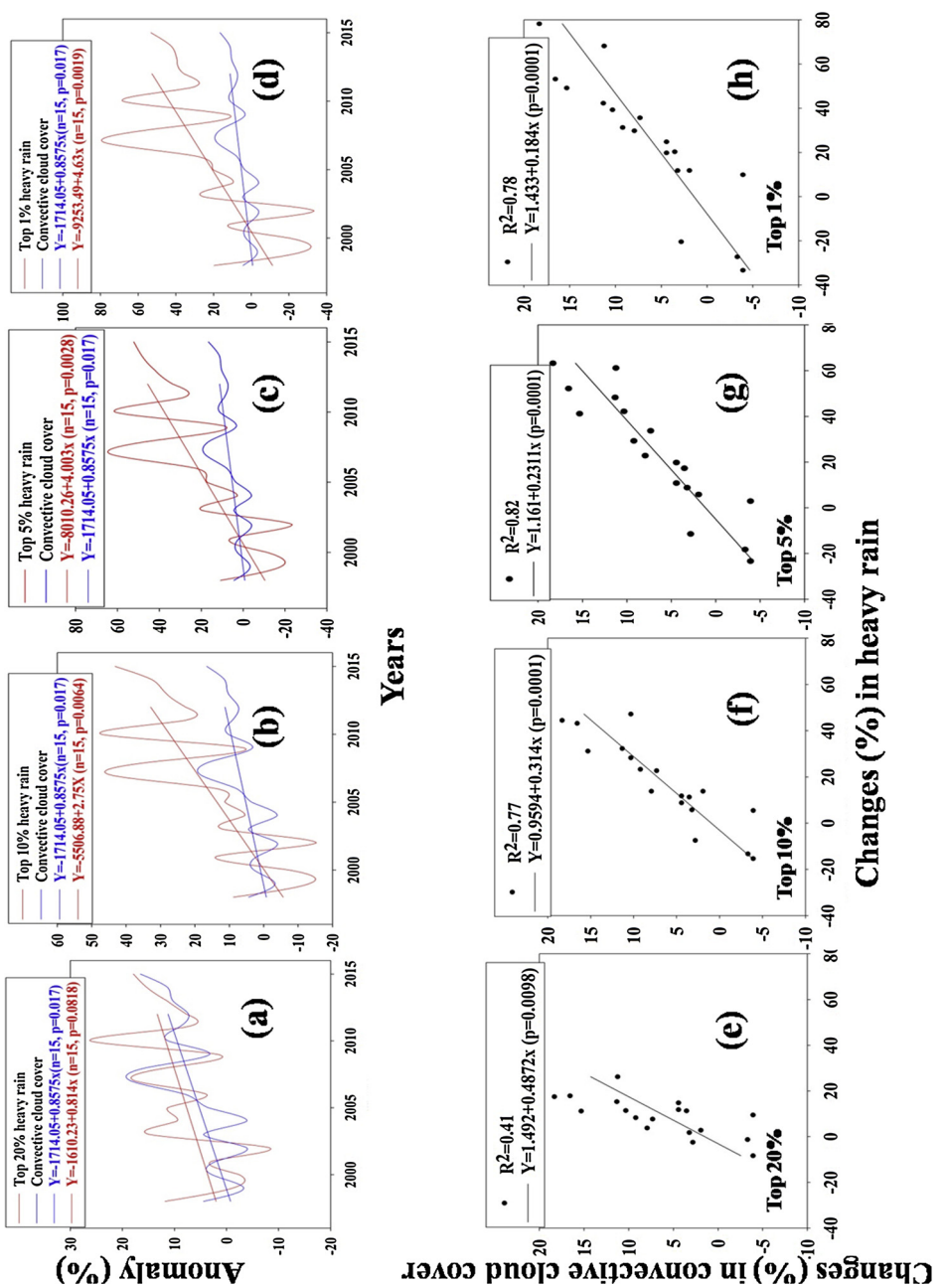


**Fig. 4.** Time series of anomaly (%) of convective cloud cover and (a) top 20% (b) top 10% (c) top 5% (d) top 1% precipitation, and scatter plot between changes (%) in convective cloud cover and (e) top 20% (f) top 10% (g) top 5% (h) top 1% precipitation.

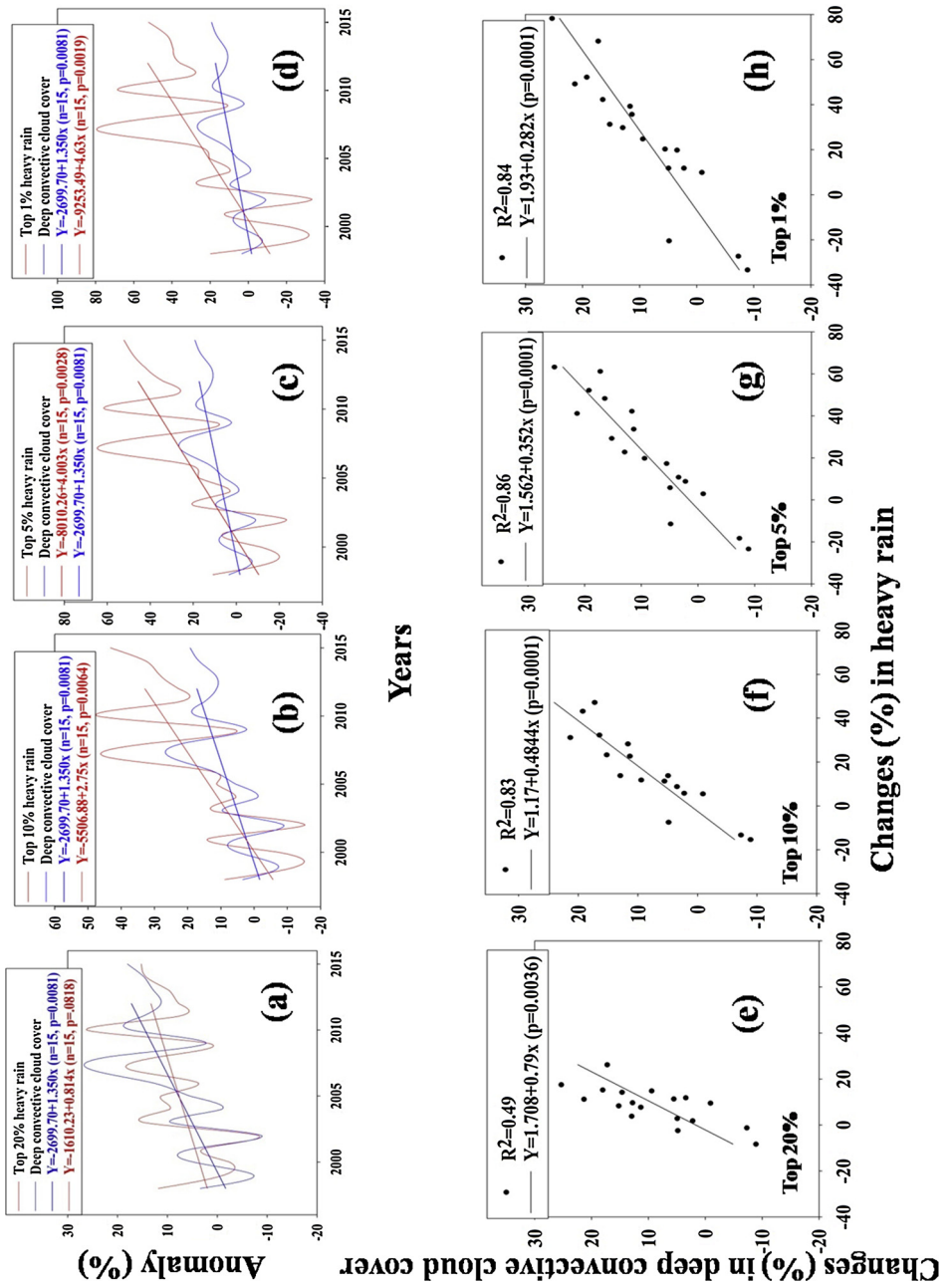


**Fig. 5.** Same as Fig. 4 but for deep convective clouds.

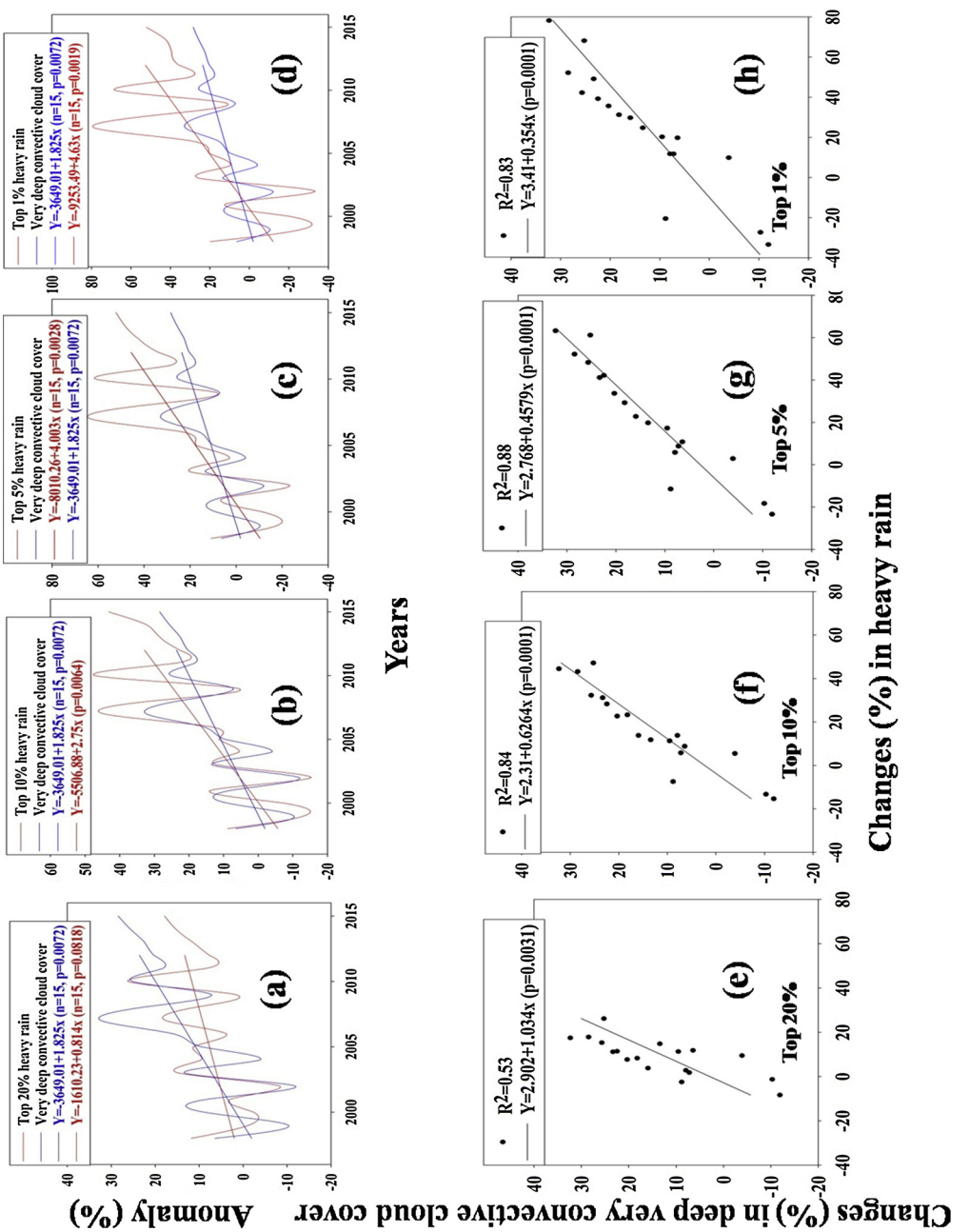


**Fig. 6.** Same as Fig. 4 but for very deep convective clouds.

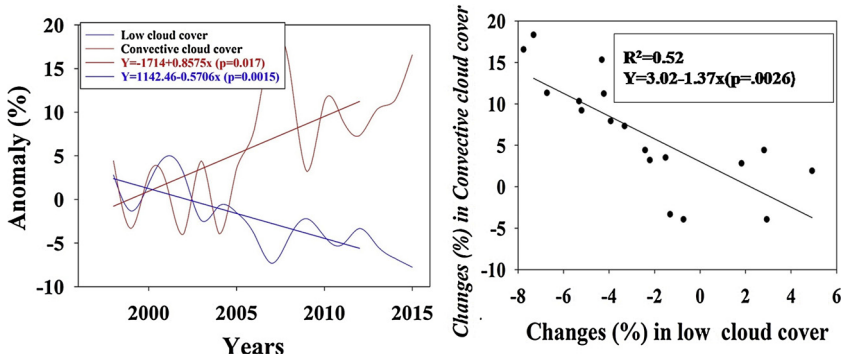


**Fig. 7.** (a) Time series of anomaly (%) of low cloud cover and convective cloud cover (b) Scatter plot between changes (%) in convective cloud cover and low cloud cover.

Equations established between changes in heavy precipitation and those in high cloud cover may be used to infer the changes in one of these variables if other one is known. These equations become crucial, given the lack of past records of cloud cover changes.

Results reported in this study show that increase in convective cloud cover have been accompanied by a decrease in low cloud cover. The possible relation between changes in convective cloud cover and those in low cloud cover is examined.

Fig. 7a shows time series of anomalies of low and convective cloud cover. A coefficient of determination of about 0.52 between changes in convective and low loud cover suggests a closed link between them. So convective cloud covers might be increased at the expense of low cloud cover. However, a good coefficient of determination does not necessarily imply a cause effect relationship. Physical cause behind these changes is too complex involving cloud microphysics and needs to be examined further.

## 5. Summary and conclusion

Satellite data (1998–2015) over Central Indian region is analyzed to explore the linkage between changes in cloud cover and precipitation extremes. These changes in cloud cover are also linked to the changes in precipitation extremes. The results presented in this paper point to increase in heavy precipitation and decrease in bottom 30% precipitation. Significant increase in convective cloud cover and decrease in low cloud cover is also reported in this study.

A good linkage between increases in convective cloud covers and those in heavy precipitation has been reported. Changes in convective cloud cover also show a good linkage with those in low cloud covers. These changes in convective cloud cover may cause a significant change in latent heat in upper troposphere which plays an important role in the atmospheric circulations as well as the radiative heat budget.

This study suggests that changes in high cloud cover and precipitation extremes are related to changes in surface air temperature. The atmospheric water vapor is projected to increase by 12–16% over large parts of Indian subcontinent (Kriplani et al., 2007) at the time of CO2 doubling. This increased moisture content can lead to enhanced convective cloud cover and precipitation extremes.

It is further suggested that the changes in cloud cover may cause a change in precipitation extremes. This does not, of course, provide a direct physical cause and effect explanation for a relation between changes in cloud cover and precipitation extremes.

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